Doppler-free spectroscopy of an atomic beam probed in traveling-wave fields

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Precision spectroscopy based on atomic beams has achieved a number of remarkable advances in the last few decades. In these precision measurements, it's critical to reduce the Doppler effect. Common methods used to align the optical beams are the cat's eye method [1] and the active fiber-based retro-reflector method [2, 3]. Although the deviation angle ξ between two counter-propagating laser beams could be adjusted to below 10 μrad, the standing-wave field could induce some challenges, such as the assessment of residual Doppler shift, the systematic deviations from differences of the two counter-propagating laser beams, the detectable laser cooling effect on the atomic beams [4], and so on.

Here we propose a method to probe the precision spectroscopy of an atomic beam using traveling-wave laser beams. We demonstrated this method by measuring the $2^3S - 2^3P$ transition in a slow helium beam [5]. The first-order Doppler shift could be effectively suppressed by up to three orders of magnitude compared to that induced by the probing light beam. This method avoids using a standing-wave field when probing the spectra, reduces the laser power dependence, and eliminates the modulation due to the standing-wave fields. Preliminary measurements of the $2^3S - 2^3P$ transition of ^4He indicate that the uncertainty could be reduced to the sub-kHz level. Combined with the latest theoretical advances [6], we expect a new determination of the nuclear charge radius of the helium nucleus. This method could also be widely applied in various precision spectroscopy experiments based on atomic of molecular beams.

[1] D. Shiner *et al.*, Phys. Rev. Lett. 72, 1802 (1994)
[2] A. Beyer *et al.*, Opt. Express 24, 17470 (2016)
[3] V. Wirthl *et al.*, Opt. Express 29, 7024 (2021)
[4] X. Zheng *et al.*, Phys. Rev. A 99, 032506 (2019)
[5] J. -J. Chen *et al.*, Phys. Rev. A 101, 053824 (2020)
[6] V. Patkóš *et al.*, Phys. Rev. A 103, 042809 (2021)

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